A Holistic Approach to HVAC Design: Balance Load Calculation and Piping for Comfort and Sustainability

Moses Ugbede David[1], Elisha Kenneth[1], Sunday Adams Tegwi[1], Nicholas Gukup[1] and Olufemi Oni[2]

[1]Department of Mechanical Engineering, University of Jos, Plateau state, Nigeria.
[2]Daikin Europe and Nigeria.

Corresponding Authors Email: davidugbede247@gmail.com,

Direct Research Journal of Engineering and Information Technology

Vol. 14(2), Pp. 20-29, June 2026,
Author(s) retains the copyright of this article
This article is published under the terms of the
Creative Commons Attribution License 4.0.
Research Article
ISSN: 2354-4155
https://journals.directresearchpublisher.org/index.php/drjeit; https://www.ajol.info/index.php/drjeit

Received 27 April 2026, Accepted 20 May 2026, Published 2 June 2026

ABSTRACT

This study presents an integrated approach to HVAC (Heating, Ventilation, and Air Conditioning) system design, combining precise load calculation with efficient piping design to achieve thermal comfort, indoor air quality, and energy efficiency. The methodology was executed in two phases. First, detailed load calculations were performed using HEVACOMP software, accounting for building orientation, insulation, occupancy, and internal heat gains. These calculations established heating and cooling requirements, guiding optimal equipment sizing. Second, piping design was developed using AutoCAD to ensure effective distribution of conditioned water and air, minimizing pressure losses and maintaining proper flow. Considerations included pipe sizing, layout optimization, insulation, and compliance with standards. Control strategies, zoning, and air distribution effectiveness were integrated to enhance comfort and operational efficiency. The study identified a peak load of 220 kW and designed a piping system tailored to departmental needs. Results demonstrate that coupling accurate load assessment with meticulous piping design yields reliable, energy-efficient HVAC systems, aligning with sustainability goals and reducing operational costs.

***keywords**: HVAC system design, Load Calculation, Piping Design, HEVACOMP and AutoCAD, Energy Efficiency, Sustainability*



Citation: David M. U., Kenneth.E., Tegwi S. A., Gukup.N. & Oni.F. (2026). A Holistic Approach to HVAC Design: Balance Load Calculation and Piping for Comfort and Sustainability. *Direct Research Journal of Engineering and Information Technology*. 14(2), Pp. 20-29. https://doi.org/10.26765/DRJEIT64580354

INTRODUCTION

Heating, ventilation, and air conditioning (HVAC) systems are essential for indoor thermal comfort, air quality, and energy efficiency. As buildings account for over one-third of global energy consumption and emissions, optimizing HVAC design is critical for sustainability and cost reduction (IEA, 2024). Modern HVAC systems are often the largest energy consumers in commercial and residential buildings, typically representing 50–60% of total building energy use (U.S. EIA, 2025). As climate concerns and energy costs rise, demand for energy-efficient systems has intensified. A holistic approach that integrates accurate load calculation with efficient piping design reduces

inefficiencies such as oversized equipment, uneven airflow, and excessive energy use (NZEB, 2023). This determines precise heating and cooling demands by accounting for building orientation, envelope performance, occupancy, internal heat gains, and local climate. Piping design minimizes pressure losses and ensures balanced flow through proper pipe sizing, routing, insulation, and control strategies (Energy Design Systems, 2024). Accurate load calculation underpins effective HVAC design and sizing. Contemporary standards and methods—such as ASHRAE guidance, the Heat Balance Method, account for dynamic factors like weather, occupancy schedules, and equipment efficiency (ASHRAE, 2021; IES, 2024). Software tools such as HEVACOMP enable granular analysis of sensible and latent loads, zone-specific demands, and annual energy variation to avoid oversizing and meet peak needs efficiently. Case studies show that optimizing building envelopes and daylighting can reduce cooling loads by 20–30%, though practical constraints (utility pricing, retrofits) can limit theoretical gains (Energy Design Systems, 2024).

Efficient piping design is equally important for reducing energy losses and maintaining uniform distribution. Proper sizing, layout, and insulation lower pump and fan energy consumption, while adherence to applicable standards (for example, ASME B31.3 for process piping) preserves system integrity. When stress analysis is required-typically for hydronic or industrial piping systems-tools such as CAESAR II can assess thermal expansion, pressure drop effects, and seismic resilience; note that CAESAR II is usually applied to industrial/hydronic piping stress analysis. Integrating load-calculation outputs with CAD-based routing (for example, HEVACOMP profiles into AutoCAD) streamlines zoning and balancing, improving operational efficiency (SlideShare, 2024). Recent advances focus on sustainability and occupant-centric control. Renewable energy integration, smart controls, predictive algorithms, and occupancy sensors enable dynamic adjustment of airflow and temperature, reducing energy use by 15–25%.

Passive measures-thermal mass, shading, and high-performance envelopes-also contribute to net-zero objectives. Nevertheless, high upfront costs and design complexity remain barriers to broad adoption. Despite these advances, few studies have demonstrated an integrated, software-driven methodology that simultaneously couples load calculation with piping design in a tropical building context. This paper addresses that gap by presenting case study of the Mechanical Engineering Department at the University of Jos, Nigeria, using HEVACOMP for dynamic load analysis and AutoCAD for piping layout, contributing a replicable design framework applicable to similar climatic regions.

METHODOLOGY

Final Recommendations

1. Add building details (floor area, occupancy density, construction type).
2. Provide thermal properties of materials (U-values, conductivity).
3. Ensure citations are complete and consistent (PDH Online, Akande et al., etc.).
4. Clarify figures and tables with proper captions and numbering.
5. Strengthen load calculation reporting by including design indoor conditions and load breakdown.

METHODOLOGY

Experimental Site

The experimental site for this study was the Mechanical Engineering Department building at the University of Jos. The facility consists of a reinforced concrete frame with 250 mm thick block walls (U-value = 1.516 W/m²K), an admittance of 4.11 W/m²K, a decrement factor of 0.3, and a time lag of 8.72 h. The building has a total floor area of approximately 1,090 m², comprises one floor, and accommodates a design population of 305 students distributed across five classrooms, fifteen offices, and three laboratories. This corresponds to an occupancy rate of approximately 3.57 m² per occupant. Additional building characteristics are presented in Table 1.

Table 1: Building Details

Total Floor Area	**1,090 m²**
Number of Floors	1
Occupancy Density (person/m²)	3.57 m²
Construction Type (e.g., reinforced frame)	Heavyweight Masonry
Year of Construction	2018

Equipment and Software Tools

Two primary software tools were used for the HVAC system design:

AutoCAD 2016

AutoCAD 2016 was used to create and verify the architectural layout of the Mechanical Engineering Department. Hard copy designs obtained from the physical facilities were digitized to determine the precise dimensions (length, breadth, height) of rooms, offices, and laboratories. This digital model served as the basis for further HVAC load calculations and piping design. The overall HVAC system design methodology adopted in this study is presented in Figure 1

HEVACOMP Design Software

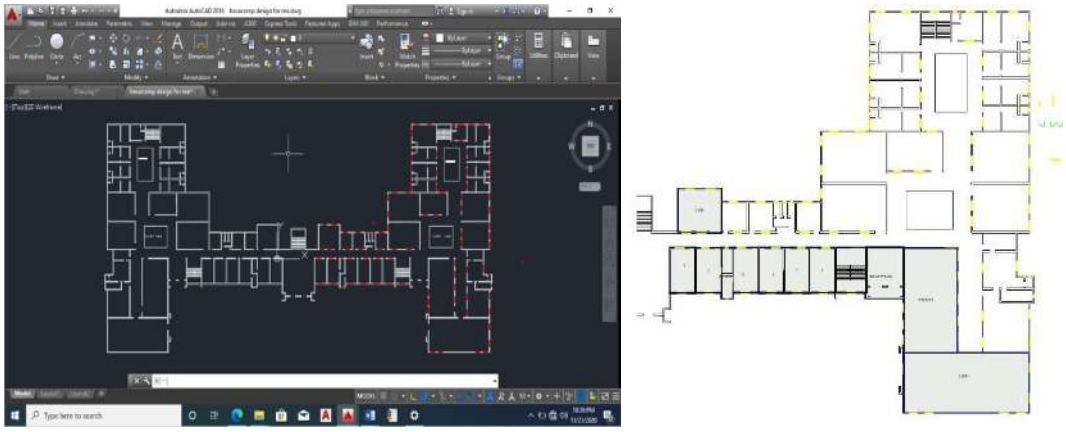


Figure 1: Procedure for HVAC System Design



Figure 2: HEVACOMP Design Database

HEVACOMP 25.00.40 Trial Version (Bentley Systems) was employed to perform automated heating and cooling load calculations for the building. The software accounts for various internal and external heat gains, including occupancy, furniture, equipment (e.g., laptops, projectors, TPS machines), and operational schedules for offices, classrooms, and laboratories. Based on these inputs, HEVACOMP calculates the total HVAC load and recommends an appropriate system to meet the department's requirements. The HEVACOMP design database interface used for inputting building and occupancy data is shown in Figure 2.

Data Input and Building Description

Using HEVACOMP, the design process began with inputting project-specific data via the software's data interface.

Project Description and Geographic Data: Location-specific information was entered, including latitude, longitude, and elevation.

Weather Data Source: The Metronome database was selected for accurate climatic data relevant to the building's location in Nigeria.

Window-to-Wall Ratio: The fraction of window area covered by glass versus aluminum framing was specified.

Surrounding Building Elevation Angle: Set at 45°, to represent a clearer solar obstruction or shading factor. In plain terms, it shows how much nearby buildings block the sun from the point being analyzed.

Occupancy Schedules: Number of days per week the building is occupied, and operational hours for the cooling

Table 2: Occupancy Schedule

Activity Type	Class Room	Office	Lab
Number of Occupants	40	15	30
Operational Hours/day	8	8	8
Days/Week	5	5	5

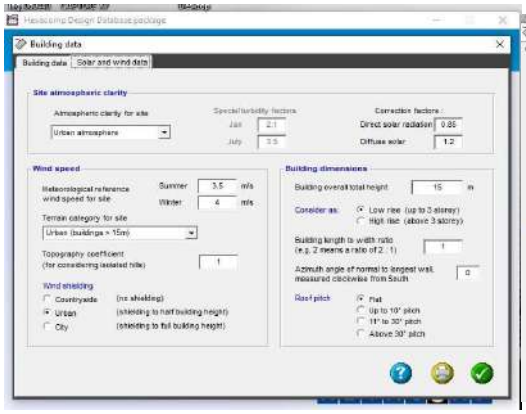


Figure 3: Solar and Wind Data

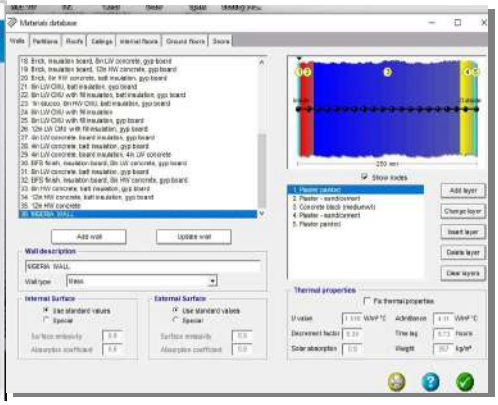


Figure 4: Fabric Data

Table 3: Thermal Properties of Materials

Layer	Thickness (mm)	Thermal Conductivity (W/m.K)	R-Value (m^2.K/W)
Plaster	20	0.57	0.035
Concrete Block	210	1.13	0.186
Plaster	20	0.57	0.035
Total	250	-	~0.256

plant was defined to simulate realistic usage patterns (Table 2).

CAD Model Import and Verification

The architectural layout designed in AutoCAD was exported as a DXF file and imported into HEVACOMP's CAD input module. The imported design was validated against architectural drawings to ensure accuracy and unit consistency between the software's.

Atmospheric and Fabric Data Input

Solar and Wind Data: Atmospheric clarity, wind speed, and other environmental parameters were entered to model external heat gains. Figure 3 significantly affects cooling demand, especially in tropical climates, and must be carefully modeled to optimize shading and glazing strategies. Studies show that solar heat gain can contribute up to 30% of total cooling load (Akande et al., 2019).

Building Fabric Composition: Wall construction details were specified, including layers of paint, plaster, concrete block, and plaster, giving a total wall thickness of 250 mm. (Figure 4) variations reflect the thermal mass behavior of building materials, which influences heat storage and release patterns throughout the day and is important for passive design and load shifting (Akande et al., 2019).

Glazing Data: Window specifications were entered, including glass type, blind or curtain arrangement, and material properties (Table 3).

Load Calculation

Using the comprehensive building data, HEVACOMP calculated the total heating, ventilation, and air conditioning load. These calculations followed ASHRAE standards to ensure accuracy and compliance with industry best practices. Load calculation methods have evolved from simple rules-of-thumb to sophisticated dynamic models incorporating building envelope, occupancy, equipment, and weather data. Techniques such as Cooling Load Temperature Difference (CLTD) and Radiant Time Series (RTS) improve precision by

Table 4: Hourly heat gain breakdown

Sun Time	Solar Load (W)	Fabric Load(W)	Convective load (W)	Latent Load(W)	Casual Load(W)	Total Load (W)
08:00	944	-57	-3	97	1687	2668
09:00	868	81	21	100	1779	2849
10:00	787	144	46	103	1789	2869
11:00	625	168	68	107	1799	2767
12:00	565	166	88	110	1864	2793
13:00	588	147	103	112	1674	2724
14:00	742	148	113	114	1808	2925
15:00	884	207	118	115	1815	3147
16:00	983	253	103	114	1826	3279
17:00	983	307	103	112	1826	3331(Peak)
18:00	9	359	88	110	1825	2373

accounting for transient heat gains (PDH Online, n.d.).

RESULTS

Heat Load Components

Solar Load (W)

Solar load represents heat gained from solar radiation entering the building through windows and other transparent surfaces. Peaks in mid-afternoon, highlighting the need for effective solar control strategies such as shading and glazing optimization (Akande et al., 2019). It depends on window orientation, size, shading, glazing, and geographic location. Therefore, the solar load values ranging from 9 W at 6:00 PM to a peak of 983 W at 4:00 PM, reflecting typical daily solar radiation cycles (Table 4).

Fabric Load (W)

Fabric load accounts for heat transfer through the building envelope (walls, roof, and floor) via conduction and convection. This shows heat loss in early morning and gain later in the day due to thermal mass effects, typical in tropical climates. Fabric load varying from -57 W (heat loss) in the early morning to 359 W (heat gain) by 6:00 PM, indicating thermal mass effects and diurnal temperature changes. Negative values represent a reduction in net cooling demand and should be interpreted as cooling savings (Table 4).

Convective Load (W)

Convective load arises from air movement and natural or mechanical ventilation inside the building. It reflects air movement and the resulting sensible heat exchange. Values range from -3 W to 118 W throughout the day, showing heat transfer due to airflow dynamics. The negative value indicates heat loss from the space due to airflow-driven heat exchange (Table 4).

Latent Load (W)

Reflects moisture transfer and the resulting humidity control. The load remains relatively stable between 97 W and 115 W, indicating consistent humidity levels (Table 4).

Casual Load (W)

Casual load includes internal heat gains from occupants, lighting, and equipment. It is the largest load component, ranging from 1,687 W to 1,825 W, consistent with continuous occupancy and equipment use (Table 4).

Total Load (W)

Total load sums all individual components, ranging from 2,373 W to 3,331 W during the day. These hourly values provide a comprehensive picture of the building's thermal load for HVAC sizing (Table 4).

Building Load Analysis;

Location: Jos, Nigeria
Design Day: May 15th
Shading: Internal shading considered; no external shading
Lighting: Fluorescent recessed lighting
Supply Air Temperature: 14°C
Fresh Air Supply: 6 L/s per person
Diversity Factors: 1.00 for people and lights
Room Focus: Room 1

Sensible and Latent Loads

Sensible load peaks at 3.22 kW at 5 PM and is lowest (2.57 kW) at 8 AM (Table 5). Latent load remains constant at 0.11 kW throughout the day (Table 5).

Fresh Air Loads:

Sensible fresh air load peaks at 0.09 kW at 2 PM; latent fresh air load peaks at 0.03 kW at 3 PM. Negative latent contribution, indicating outdoor air provided de-humification (Table 5).

Table 5: Hourly cooling load data

Sun time	Outside Temp (°C)	Building load (sensible, kW)	Plant Total Load (kW)
08:00	22.8	2.57	2.55
12:00	20.8	2.58	2.71
15:00	31.5	3.03	3.25
17:00	30.6	3.22	3.45 (Peak)
18:00	29.5	2.26	2.46

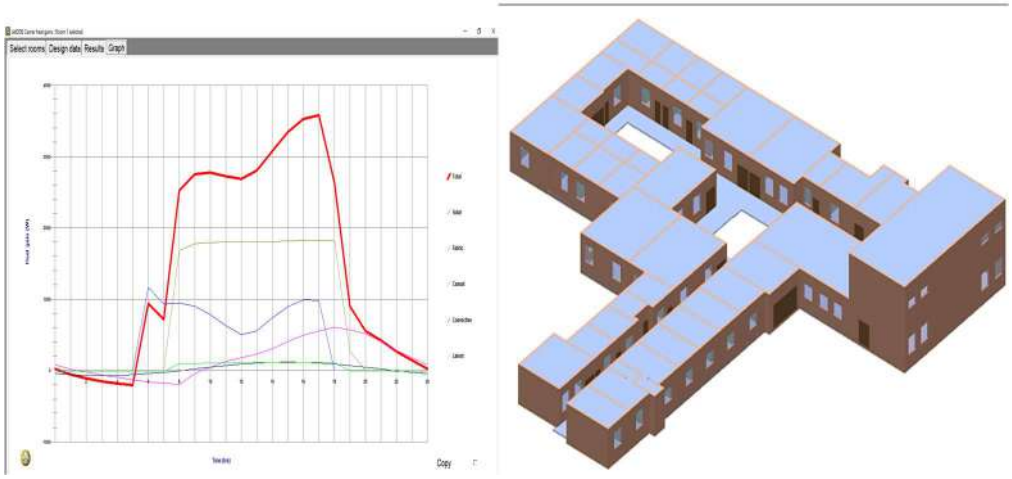


Figure 5: 3D View of The Department from HEVACOMP Soft After Full Trace

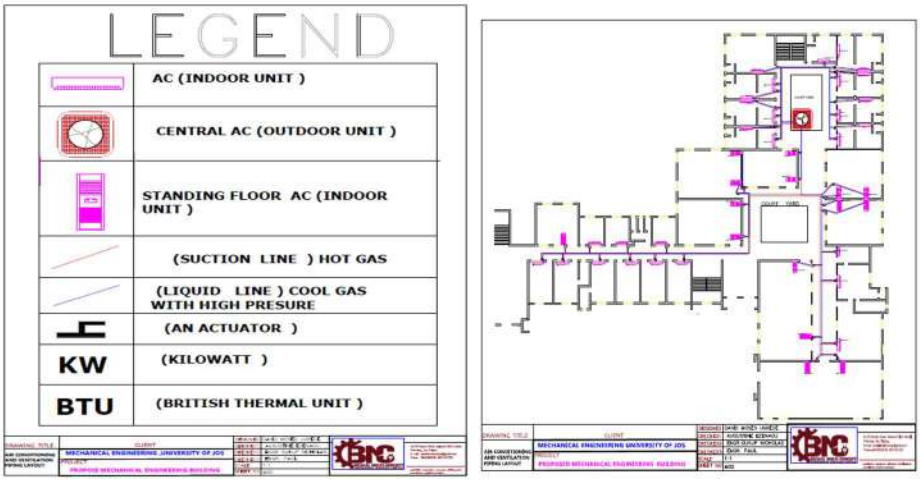


Figure 6: Building Layout

Plant Loads:

Sensible plant load peaks at 3.33 kW at 5 PM; latent plant load remains minimal (Table 5).

Airflow Rates:

Supply air and fresh air flow rates are critical for maintaining comfort and indoor air quality. The generated building model and system layout are shown in Figures 5 and 6.

HVAC System Components:

Outdoor Unit (Condenser): Houses compressor and condensing coil for refrigerant cooling.

Indoor Units (Evaporators): Located in each zone,

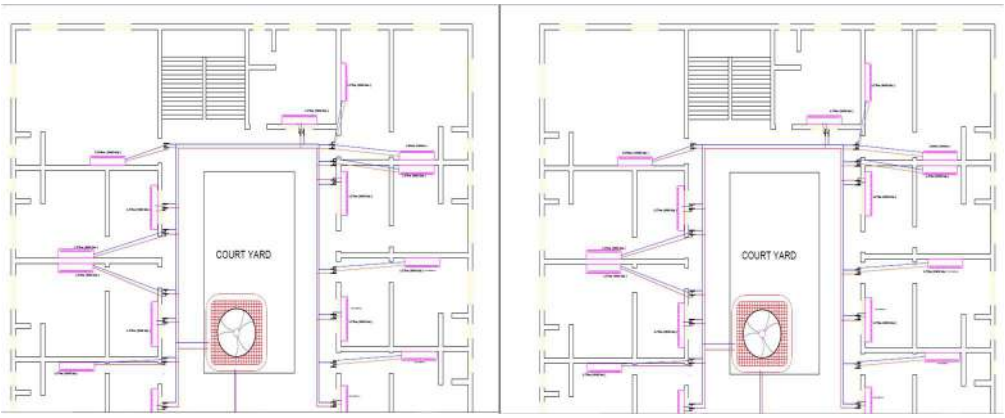


Figure 7: Full Piping and Working Drawing for the Calculated Load

containing cooling coils and fans; controlled individually for temperature settings.

Refrigerant Lines: Connect indoor and outdoor units, transporting refrigerant in liquid and vapor phases.

Suction Line: Transports low-pressure refrigerant vapor back to compressor.

Liquid Line: Transports high-pressure liquid refrigerant to expansion valve (Figure 7).

DISCUSSION

Discussion of HVAC Load Calculation Results

Overview of Load Components Analysis

The HVAC load calculation results demonstrate the complex thermal dynamics affecting the building throughout the operational period from 8:00 AM to 6:00 PM. The analysis reveals distinct patterns in various load components that are critical for understanding system requirements and optimization opportunities.

Solar Load Analysis

The solar load data shows significant variation throughout the day, ranging from 0 W at 6:00 PM to a peak of 983 W at 4:00 PM. This pattern follows the expected solar radiation cycle, with morning loads of 944 W at 8:00 AM, building to maximum values during mid-to-late afternoon hours. The solar heat gain represents a substantial contribution to the overall cooling load, particularly during peak daylight hours. The zero value at 6:00 PM indicates the analysis period extends to the end of meaningful solar contribution, which is consistent with building orientation and seasonal considerations for the Jos, Nigeria location, where mean annual temperature is 26.9°C with significant diurnal variation (World Bank, 2024).

The solar load variation demonstrates the importance of fenestration design and solar control strategies. Peak solar gains of nearly 1 kW highlight the potential for significant energy savings through proper window selection, shading devices, and building orientation optimization, as demonstrated in studies of building energy efficiency in Nigerian climatic zones (Akande et al., 2019).

Fabric Load Characteristics

The fabric load results show an interesting progression from negative values (-57 W) in the early morning to positive values reaching 350 W at 6:00 PM. The negative morning values indicate heat loss through the building envelope when outdoor temperatures are cooler than indoor conditions. As outdoor temperatures rise throughout the day, the fabric load becomes increasingly positive, representing heat gain through conduction and convection processes.

This thermal behavior is typical for buildings in tropical climates where diurnal temperature variations create shifting heat transfer directions through the building envelope. The steady increase from morning to evening suggests the building envelope's thermal mass is storing and releasing heat, creating a delayed thermal response pattern commonly observed in Nigerian climatic conditions (Akande et al., 2019).

Convective and Latent Load Patterns

The convective load follows a similar pattern to fabric load, transitioning from negative values (-3 W) to positive values (116 W maximum). This pattern reflects the air movement and natural convection processes within the building as temperature differentials change throughout the day. The latent load remains relatively stable, ranging from 97 W to 115 W, with minimal variation compared to other load components. This stability suggests consistent humidity conditions and occupancy patterns. The steady latent load indicates that moisture control requirements are predictable, which is advantageous for HVAC system

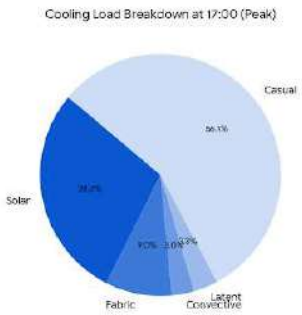


Chart 1: Since the casual load is listed as a single value (1925 W at peak). using the following formular; $Q_{person} = Q_{casual} - Q_{equipment} / N_{people}$

sizing and control strategies. The fresh air supply rate of 6 liters per second per person aligns with ANSI/ASHRAE Standard 62.1-2022 requirements for acceptable indoor air quality (ASHRAE, 2022).

Casual Load Dominance

Chart 1 represents the casual load represents the largest component of the total load, ranging from 1,687 W to 1,825 W. These values encompass internal heat gains from lighting, equipment, and occupants. The relatively high and consistent casual loads suggest significant internal heat generation, which is typical for academic or office buildings with continuous occupancy and equipment operation. The dominance of casual loads over environmental loads indicates that internal heat generation management should be a priority for energy efficiency improvements in buildings within Nigerian climatic zones (Akande et al., 2019).

Building Load Performance

Peak Load Identification

Table 5 identified a peak coincident plant load of 3.61 kW at 17:00 hours (5:00 PM). This timing coincides with the combination of high solar loads, maximum fabric heat gain, and continued internal heat generation from occupancy and equipment operation.

Sensible vs. Latent Load Distribution

The sensible load varies from 2.38 kW (8:00 AM) to 3.24 kW (5:00 PM), representing the majority of the cooling requirement. The latent load remains constant at 0.11 kW throughout the analysis period, indicating minimal moisture load variation. This 97% sensible to 3% latent ratio is typical for commercial buildings in semi - arid climates with moderate humidity levels.

Fresh Air Load Impact

The fresh air sensible load peaks at 0.09 kW at 2:00 PM, representing approximately 2.7% of the total plant load. The latent fresh air load shows minimal variation, with values ranging from -0.07 kW to 0.03 kW. The negative morning values suggest that outdoor air conditions are actually beneficial for dehumidification during early hours.

System Design Implications

Equipment Sizing

The peak coincident load of 3.61 kW provides the basis for cooling equipment selection. However, proper equipment sizing should consider safety factors and future load growth [*Reference needed: ASHRAE Load Calculation Applications Manual*].

Fresh Air Requirements

The fresh air supply rate of 6 liters per second per person aligns with ANSI/ASHRAE Standard 62.1-2022 requirements for ventilation and acceptable indoor air quality (ASHRAE, 2022). The relatively low fresh air load contribution suggests opportunities for increased ventilation rates without significant energy penalties during certain operating hours.

Supply Air Temperature Optimization

The 14°C supply air temperature represents an appropriate selection for the calculated loads and climate conditions. This temperature differential allows for adequate sensible cooling while maintaining reasonable air flow rates (Table 5).

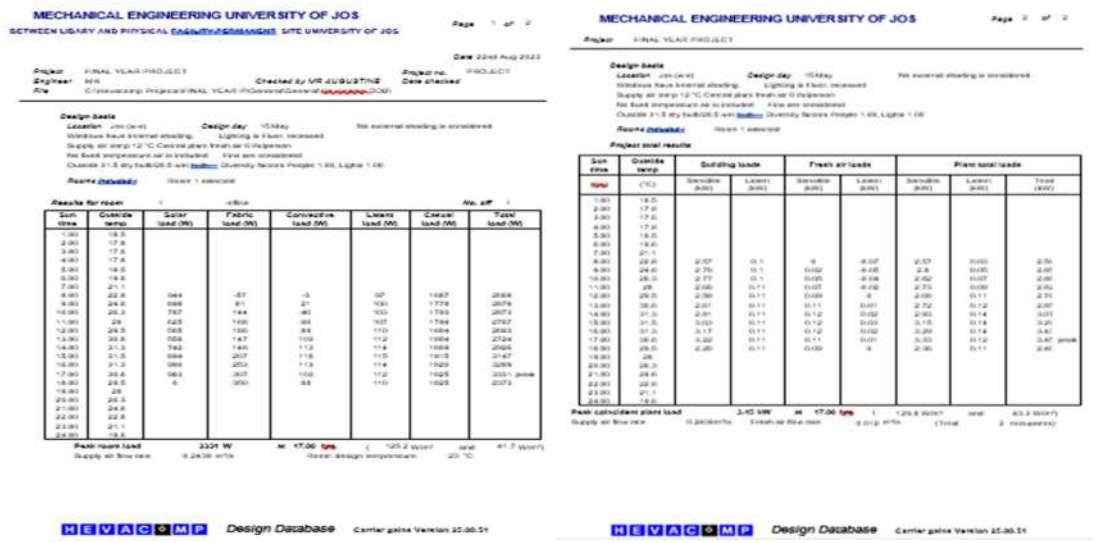


Figure 8: Energy Efficiency Improvement Opportunities in the Proposed HVAC System

Energy Efficiency Opportunities

The major opportunities for improving HVAC system performance and reducing energy consumption are summarized in (Figure 8). Figure 8 illustrates how solar control measures, thermal mass utilization, and internal load management can contribute to reducing cooling demand and improving overall system efficiency. The results obtained from Tables 4 and 5 and the final system design shown in Figure 7 reveal several opportunities for energy optimization:

Solar Control: Given the significant solar load contribution (up to 983 W), enhanced shading or glazing improvements could substantially reduce cooling requirements.

Thermal Mass Utilization: The fabric load patterns suggest opportunities for thermal mass optimization to shift peak loads to off-peak periods.

Internal Load Management: The dominant casual loads indicate potential for energy-efficient lighting and equipment selection to reduce cooling requirements.

Recommendation

The Mechanical Engineering building at the University of Jos needs a HVAC system that can provide at least 220 KW (about750,000 BTU) of cooling. This number comes from careful calculations using size, number of people, equipment, sunlight and climate. Choosing a system with capacity is important to keep the building comfortable and avoid wasting energy. A system that is too small wont cool well and one that is too big will use too much power. In this case, a water-cooled chiller or central air conditioning system is a good choice because they work well for large cooling needs. Therefore, using the right system will help to save energy and reduce costs over time. It also set a good foundation for future improvement like better insulation or more efficient equipment.

CONCLUSION

This study successfully applied HEVACOMP 25.00.40 Trial Version and AutoCAD 2016 software to perform detailed HVAC load calculations and piping design for the Mechanical Engineering Department building. The peak cooling load was accurately determined as 220 kW, guiding appropriate equipment sizing. The integration of load calculation with piping design ensured optimized fluid flow and minimized pressure drops, enhancing system efficiency. The combined use of these advanced tools significantly improved design accuracy and reduced calculation time compared to manual methods, resulting in a reliable, energy-efficient HVAC system tailored to the building's needs.

REFERENCES

Akande, O. K., Fakinle, B. S., Odetoye, T. E., Ayoola, M. A., Sonibare, O. O., & Adedeji, P. A. (2019). Building energy efficiency in Nigeria major climatic zones. *Scientific Reports in Engineering*, 4(2), 88622. https://www.scirp.org/journal/paperinformation?paperid=88622.

ASHRAE Weather Data Center. Available at: https://www.ashrae.org/technical resources/bookstore/weather-data-center

ASHRAE. (2021). *ASHRAE Handbook - Fundamentals*. American Society of Heating, Refrigerating and Air-Conditioning Engineers.

ASHRAE. (2021). *Load Calculation Applications Manual* (2nd ed.). American Society of Heating, Refrigerating and Air-Conditioning Engineers. Available at: https://www.ashrae.org/technical-resources/

bookstore/load-calculation-applications-manual
ASHRAE. (2022). *ANSI/ASHRAE Standard 62.1-2022: Ventilation for Acceptable Indoor Air Quality*. American Society of Heating, Refrigerating and Air-Conditioning Engineers.
IEA. (2024). *Buildings - Energy System*. International Energy Agency. Retrieved from https://www.iea.org/energy-system/buildings
IES. (2024). *ASHRAE Heating & Cooling Load Calculations*. Integrated Environmental Solutions. Retrieved from https://www.iesve.com/discoveries/view/10017/ashrae-heating-and-cooling-load-calculations
U.S. Energy Information Administration (EIA). (2025). *Annual Energy Outlook 2025*. U.S. Department of Energy. Retrieved from https://www.eia.gov/outlooks/aeo/
World Bank. (2024). Nigeria - Climatology. *Climate Change Knowledge Portal*. Retrieved from https://climateknowledgeportal.worldbank.org/country/nigeria/climate-data-historical
NZEB. (2023). HVAC Load Calculation and Reduction. https://nzeb.in/knowledge-centre/hvac-2/load calculation/
Energy Design Systems. (2024). HVAC Load Calculator Optimizes System Performance. https://www.eds.tech/hvac-load-calculator-optimizes-system-performance/
PDH Online. (n.d.). HVAC – Practical Basic Calculations. https://www.pdhonline.com/courses/m378/m378content.pdf
SlideShare. (2024). HVAC Heating Load - Cooling Load Calculation. https://www.slideshare.net/slideshow/hvac-heating-load-cooling-load-calculation ppt/273942871